Fast Photon Sensors for the PANDA DIRC at FAIR

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on behalf of the PANDA Cherenkov group

- Introduction
- PANDA DIRC
- Photon sensors
- Summary

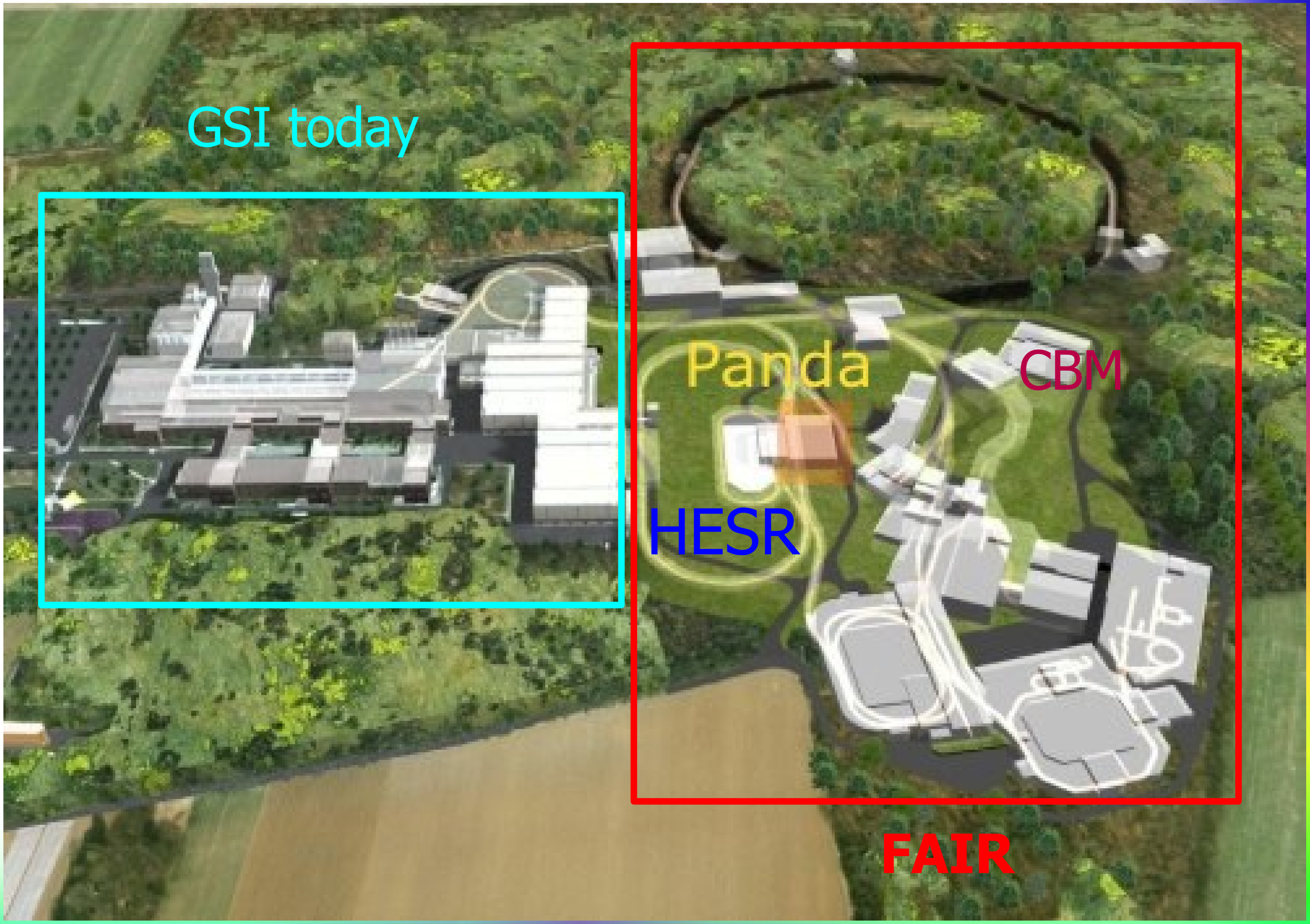
supported by BMBF and GSI

New Accelerator Facility FAIR at GSI

FAIR = Facility for Antiproton and Ion Research

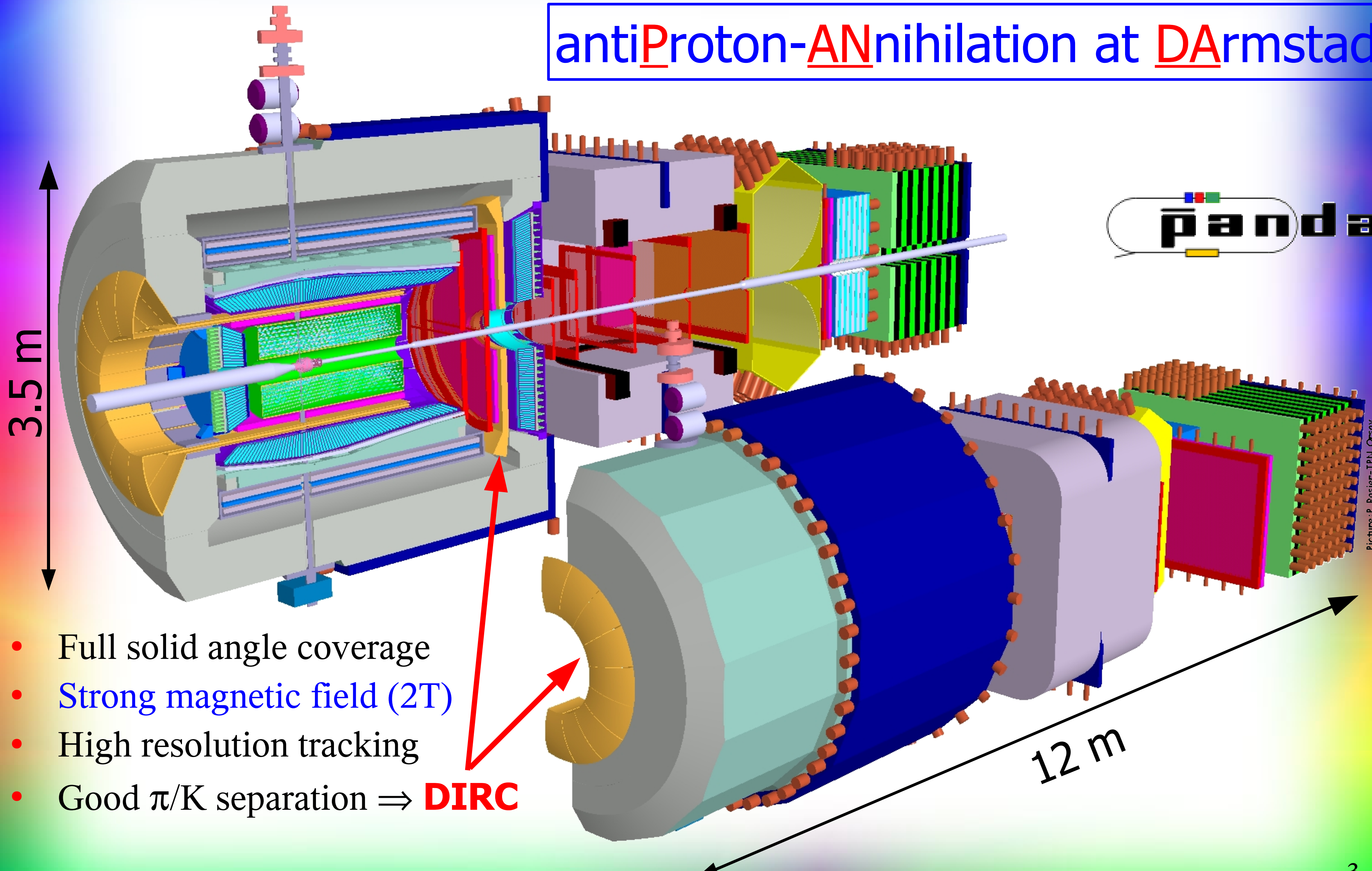
HESR =
High Energy
Storage Ring

- 1 - 15 GeV/c cooled antiprotons
- momentum resolution up to $\delta p/p \sim 10^{-5}$
- annihilation rate 10^7 Hz
- **PANDA**



PANDA Detector

antiProton-ANnihilation at DArmstadt



- Full solid angle coverage
- Strong magnetic field (2T)
- High resolution tracking
- Good π/K separation ⇒ **DIRC**

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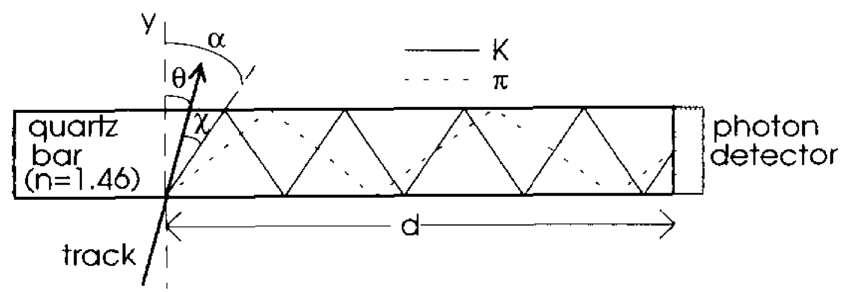
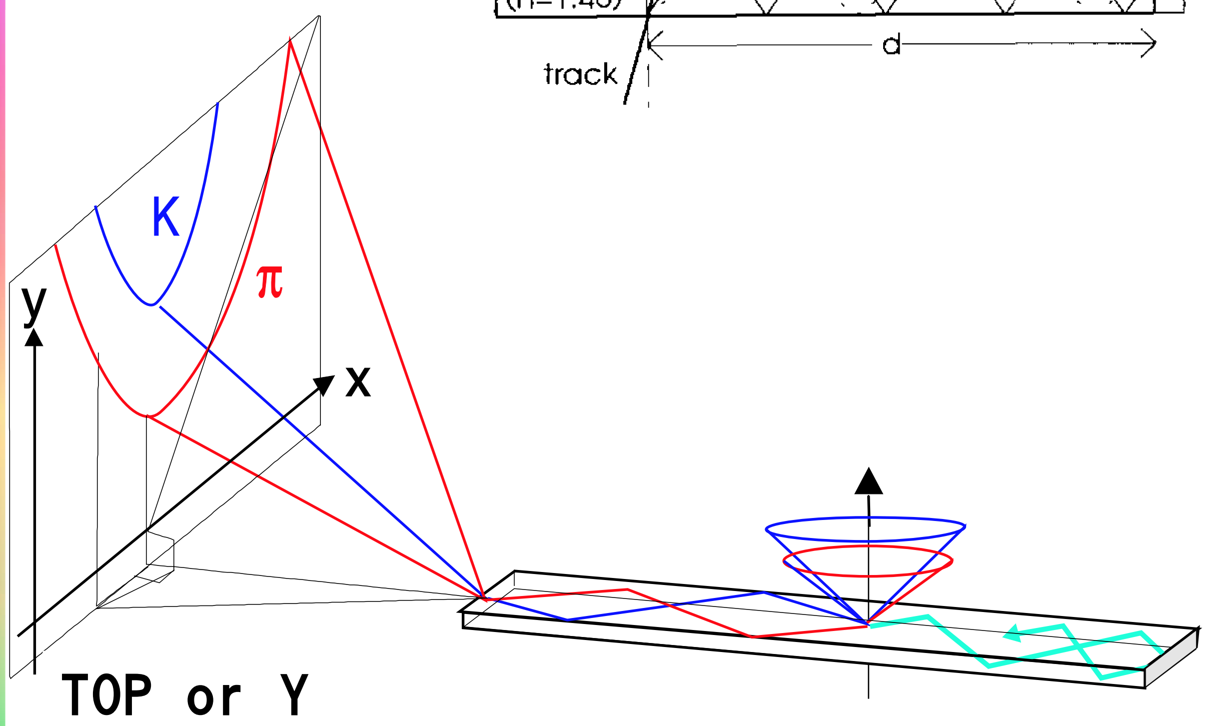
DIRC Working Principle

DIRC = Detection of Internally Reflected Cherenkov Light





Cherenkov angle:

$$\cos\chi = \frac{1}{\beta n}$$

Angle of photon hitting boundary:

$$\alpha = \chi + \theta$$

Photon path length inside quartz:

$$L = \frac{d}{\sin\alpha}$$

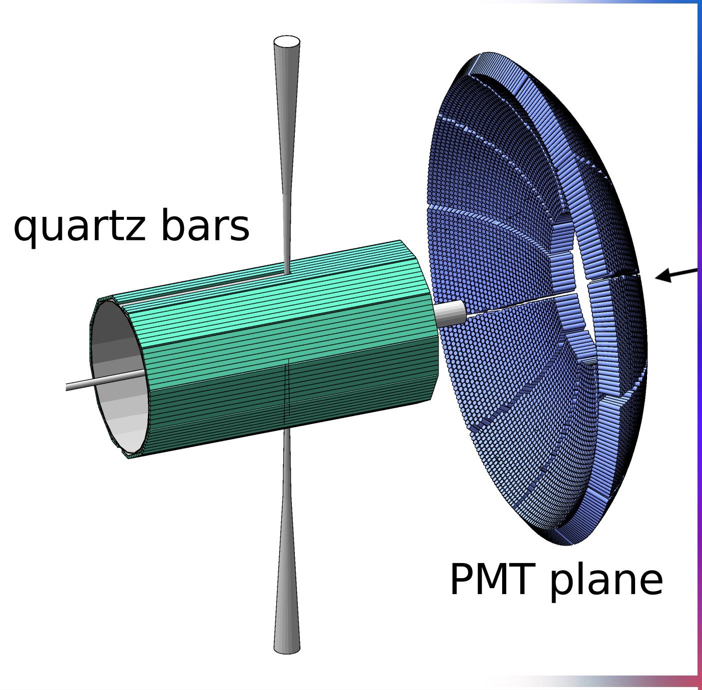
Time of propagation (TOP):

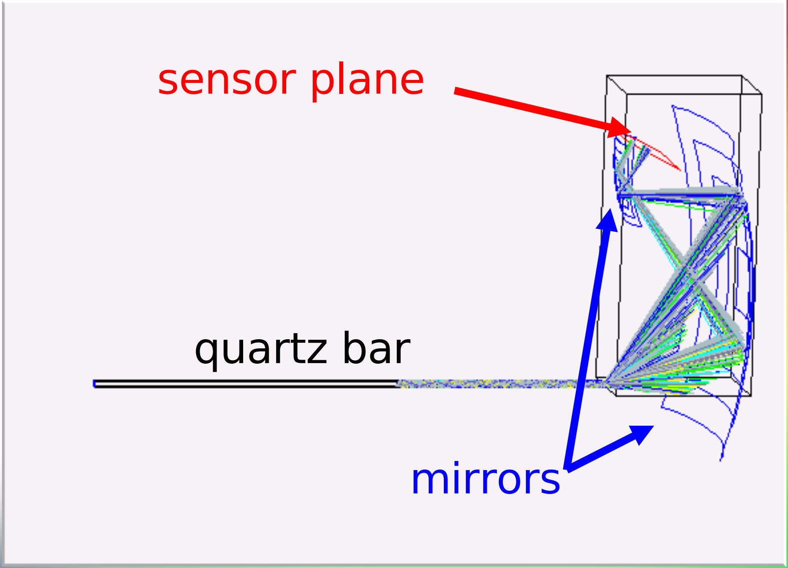
$$TOP = \frac{n\ d}{c \cdot \sin(\chi+\theta)}$$

Barrel DIRC

- scaled BaBar version (fallback solution)
  - 7000 instead of 11000 standard PMTs
  - TOP to suppress background
  - 2-dim. readout: X and Y (and TOP)

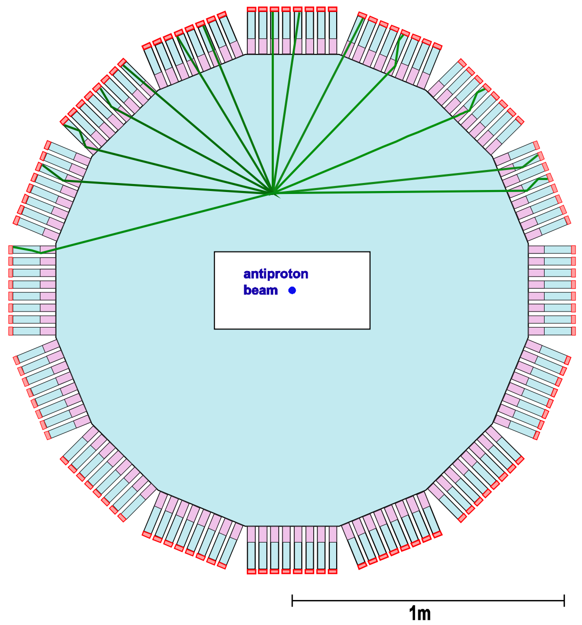
- R&D for 3D version
  - decrease projection volume by using mirrors → focal plane inside PANDA solenoid
  - photon sensors B-field resistent and position sensitive → multi-anode MCPs or SiPMs
  - 3-dim. readout: X, Y and TOP
  - X, Y to reconstruct Cherenkov angle
  - TOP information to correct for dispersive effects (feasibility recently proven at SLAC)

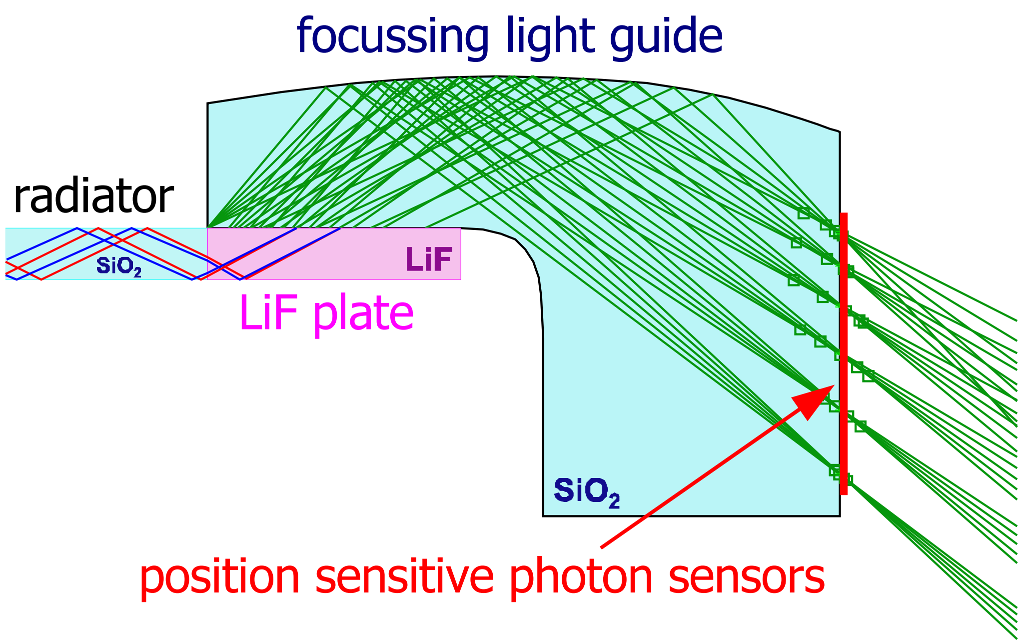


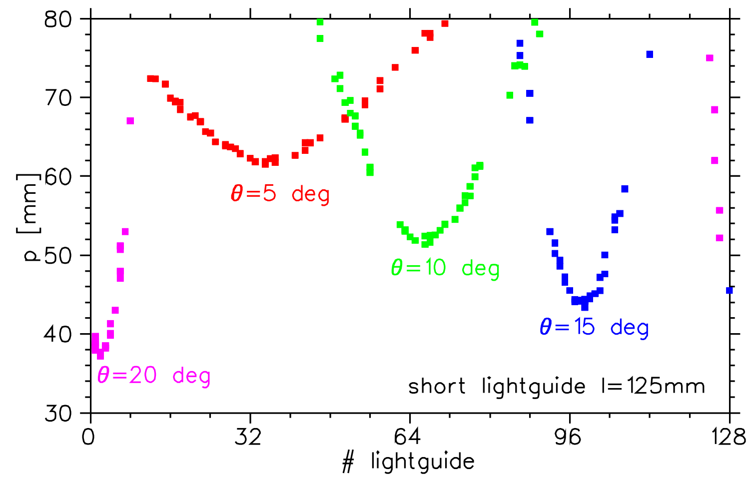


Endcap DIRC (focussing design)

- focussing system
  - **LiF plate**: correction for chromatic effects
  - **light guide**: special shape to focus the photons onto the image plane
  - **photon sensor**: pixelised to resolve the position
- 3-dim. readout: θ, φ and TOP

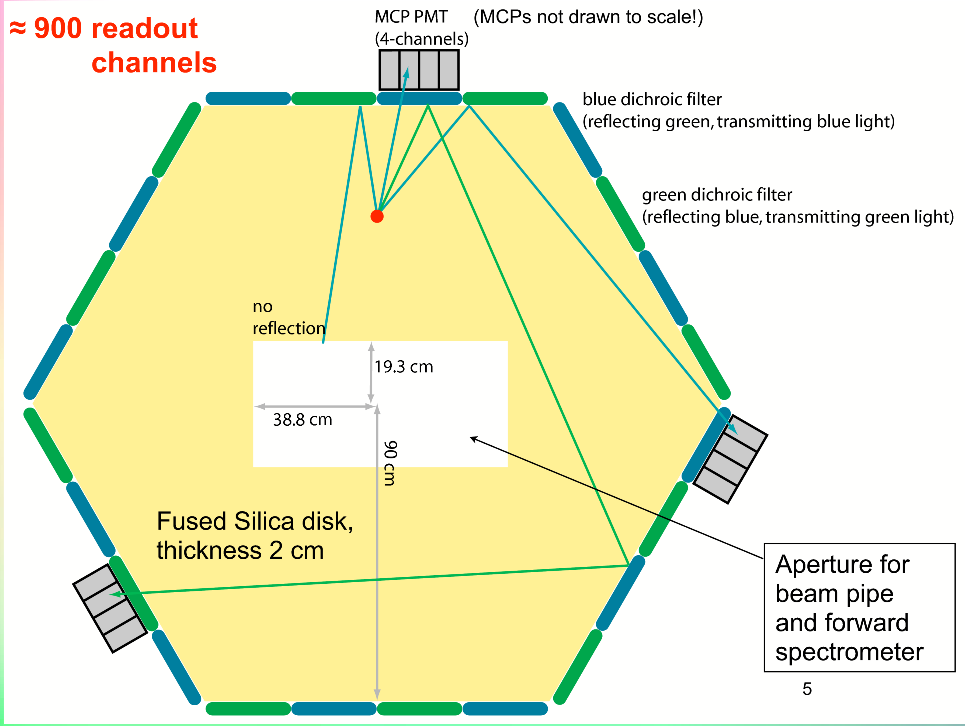


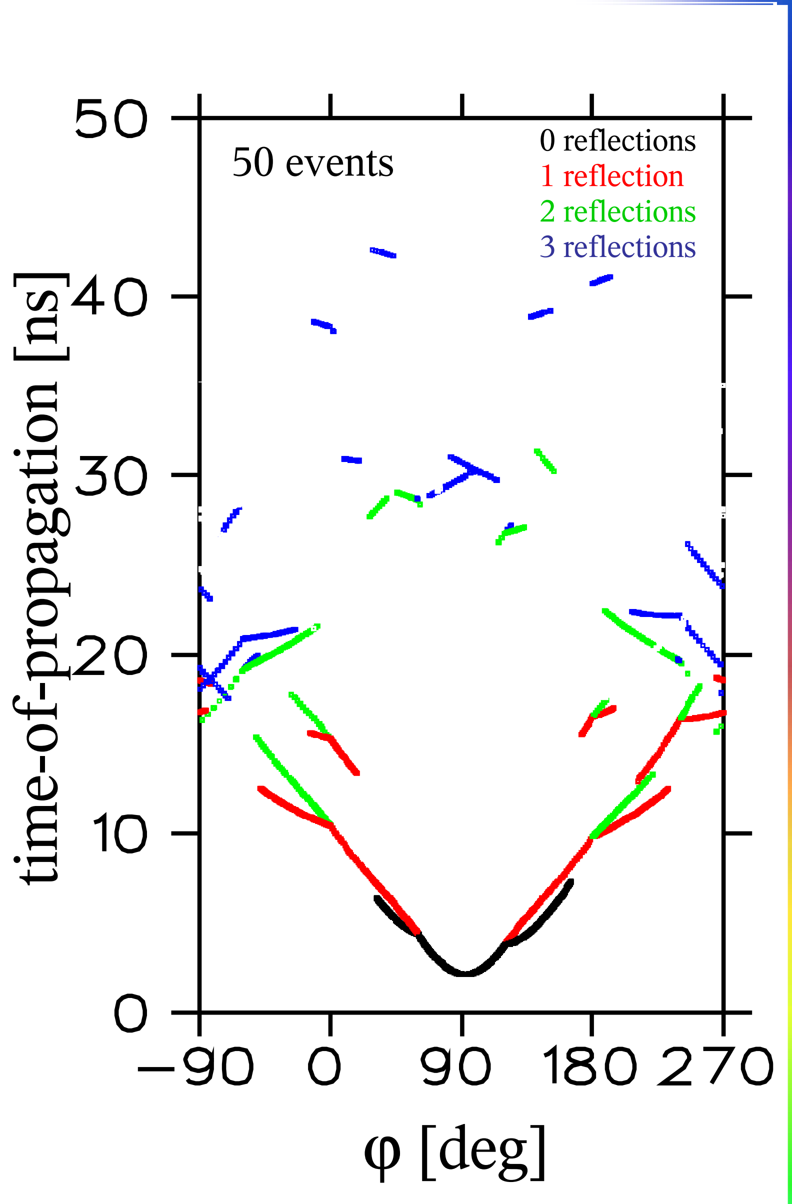




Endcap DIRC (TOP design)

- Dichroic filters in front of photon sensors
  - less problems with chromaticity
  - longer TOP for reflected photons
  - better π/K separation
  - self timing
- 2-dim. readout: φ and TOP





Technical Challenges to Photon Sensors

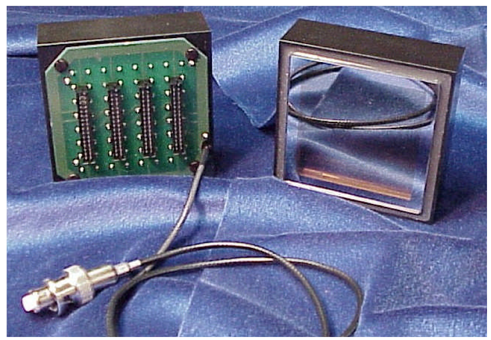
- Photon rates in the MHz regime
  - high rate stability (several MHz/cm^2)
  - long lifetime
- Few photons per track
  - high detection efficiency η = QE * CE * GE
    [QE = quantum efficiency; CE = collection efficiency; GE = geometrical efficiency]
  - low dark count rate
- Efficient single photon detection in high B-field
  - high gain ($> 5*10^5$) in an up to 2 Tesla magnetic field
- Time resolution to separate π/K with TOP
  - very good single photon transit time resolution of < 50 ps

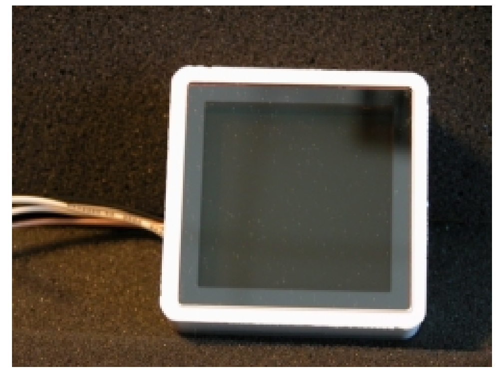
Comparison of Sensor Performances

	Standard PMT	MCP-PMT	SiPM	
Gain	1 – 100	0.1 – 10	0.1 – 1	$*10^6$
B-field	< 0.05	2	> 2	T
TTS	>> 150	< 50	~ 100	ps
Max. Rate	> 10	1 – 10	??	MHz/cm²
Dark Count	< 0.1	~ 10	> 100 / mm²	kHz
Efficiency	> 15	~ 10	< 10	%
Lifetime	> 1000	~ 1	??	C/cm²
Price	~ 100	100 – 1000	> 2000	€/cm²

There is <u>no</u> ideal candidate !

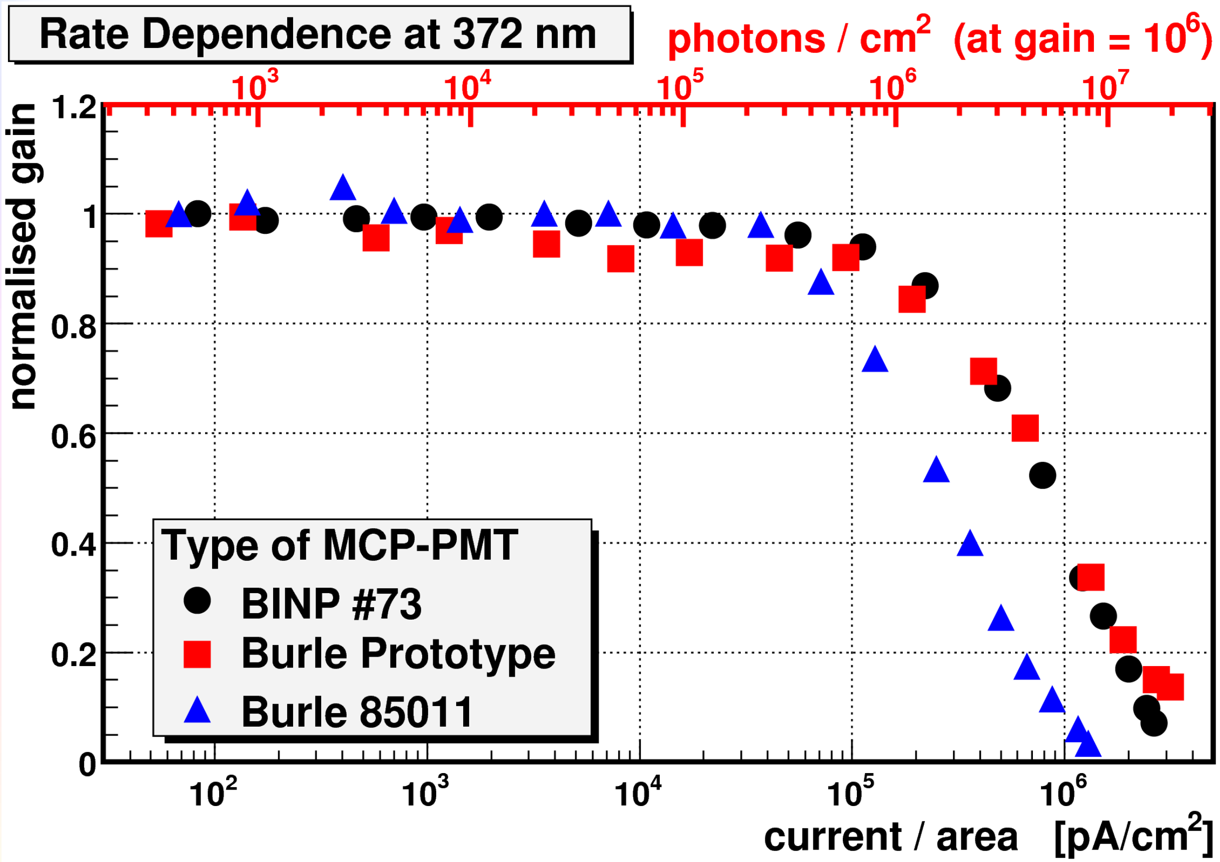
Studied MCP-PMTs

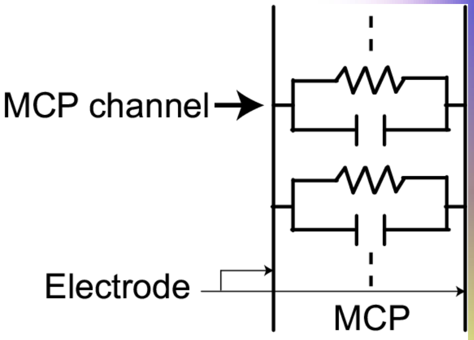




	Burle 85011	**Burle Prototype**	**BINP #73**
MCP channel diameter (μm)	25	10	6
Peak wavelength (nm)	400	400(?)	500
Active area (mm x mm)	51 x 51	51 x 51	$9^2 \pi$
Number of pixels	64 (8 x 8)	64 (8 x 8)	1
Pixel size (mm x mm)	5.9 x 5.9	5.9 x 5.9	$9^2 \pi$
Geometrical efficiency	0.44	0.47	0.36
Protection of photo cathode	No	No	5-9 nm Al_2O_3

Rate Dependence of Gain



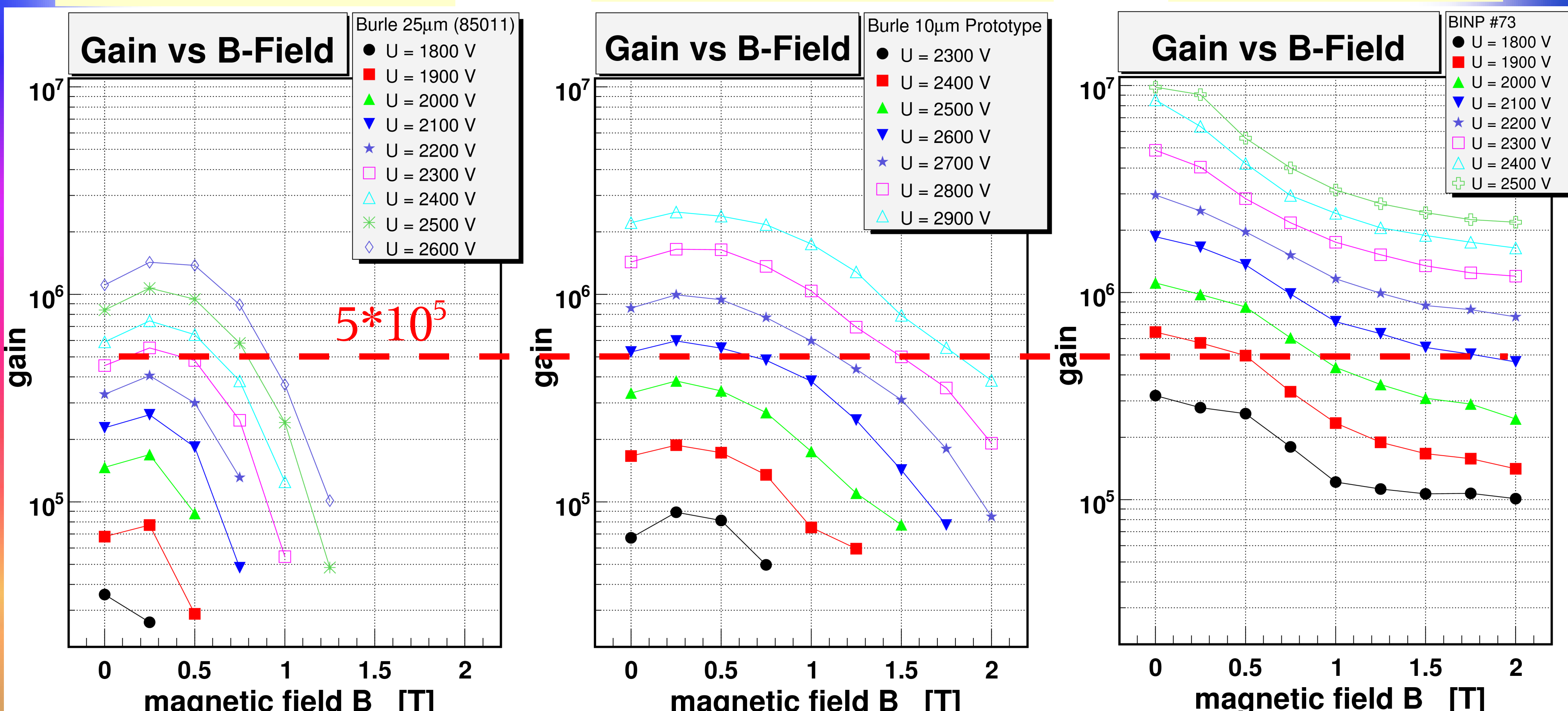


- gain drops at high rates
  - $>10^6$ photons/cm²/s
  - current flow limited in MCP pores
    → dependent on R and C

- lower RC
  ⇒ more rate

Gain in Magnetic Field

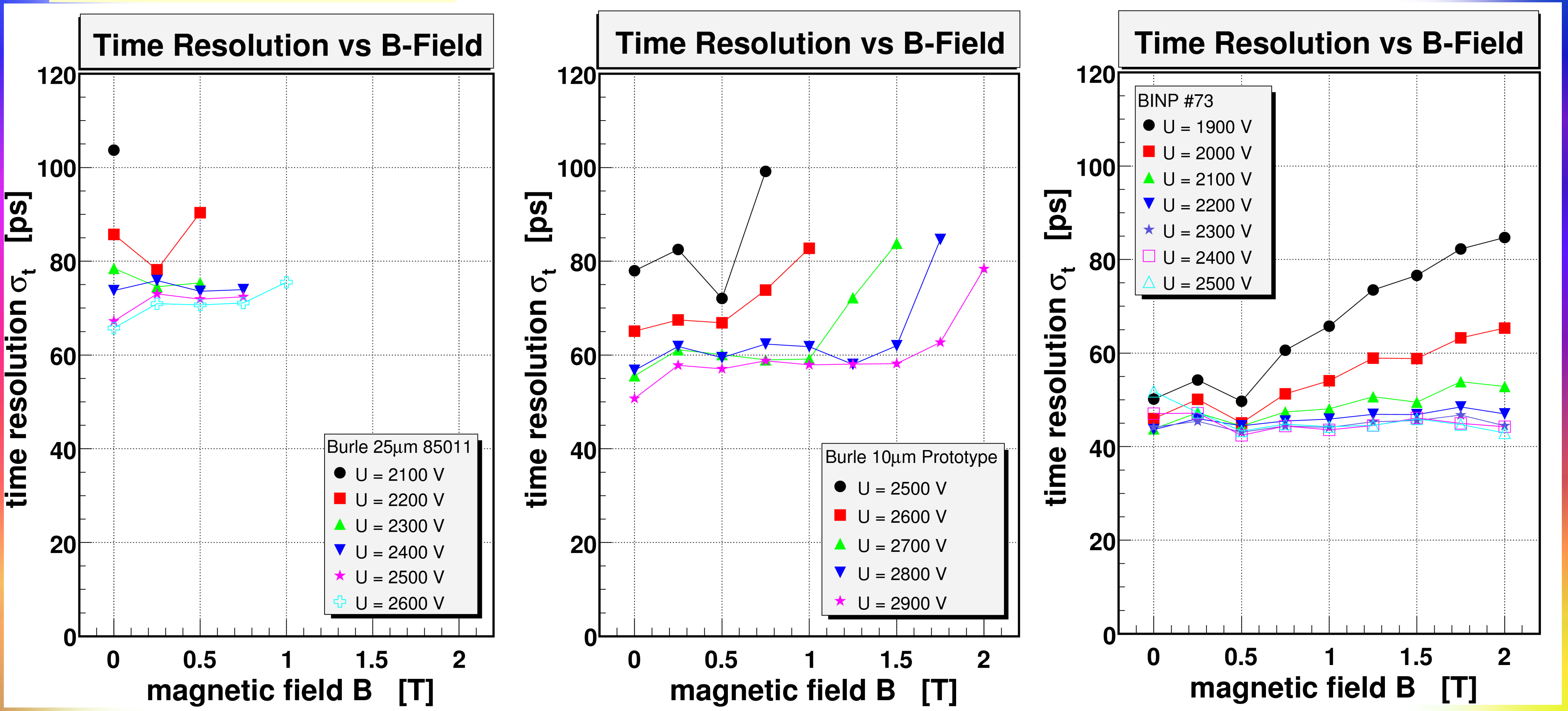
Burle 85011 (25µm) | Burle Prototype (10µm) | BINP #73 (6µm)



- gain of Burle 85011 collapses above 1 Tesla field
- Burle 10 µm prototype can be used for single photon detection up to 2 Tesla
- moderate voltages enough for single photon detection with BINP #73

Time Resolution in Magnetic Field

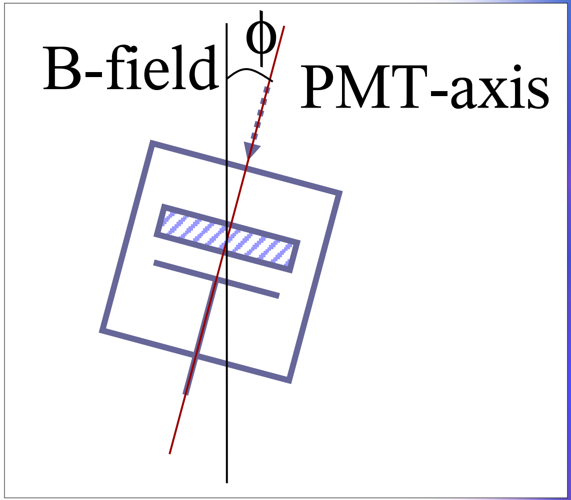
Burle 85011 (25µm) | **Burle Prototype (10µm)** | **BINP #73 (6µm)**

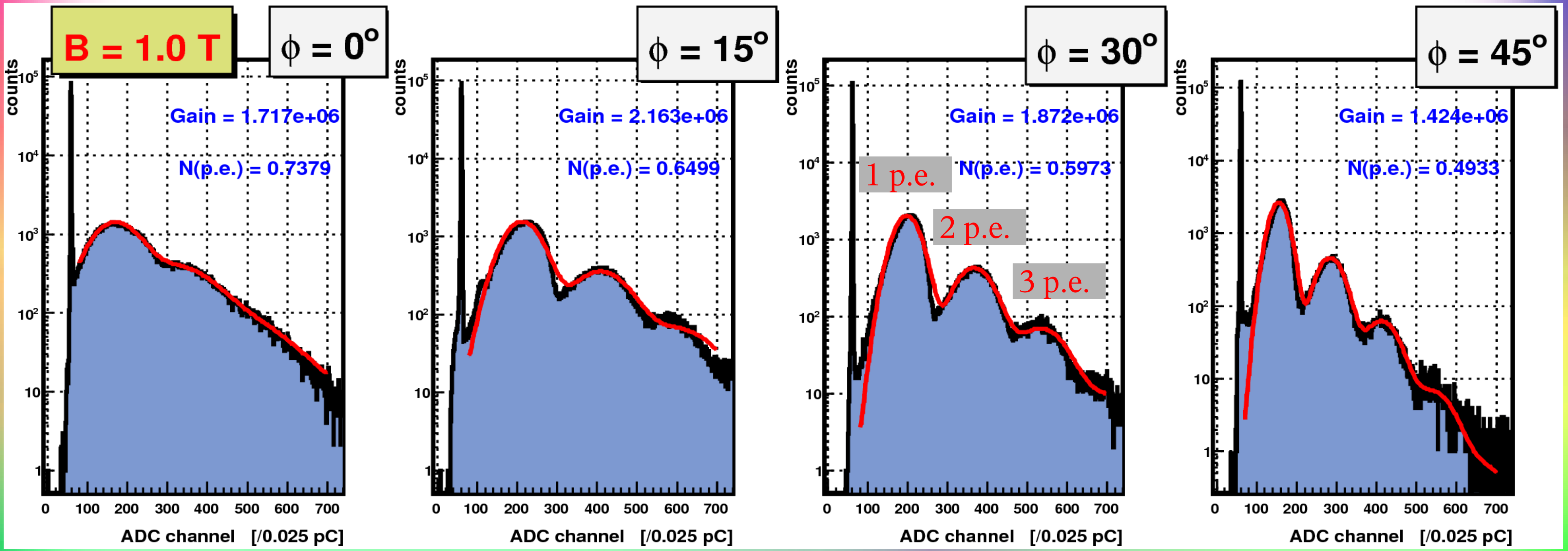


- all given time resolutions show upper limits (< 80 ps)
- time resolution improves with MCP channel diameter
- time resolution appears to be almost independent of B-field

Variation of the Field Axis

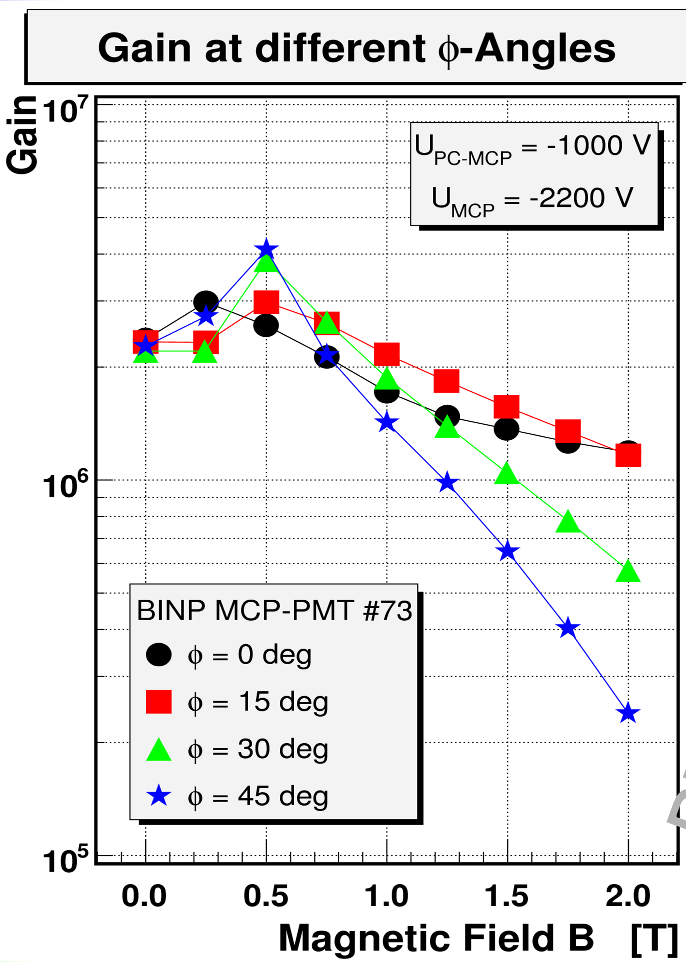
- ϕ = angle between field direction and PMT axis
- Photo electron peaks become asymmetric
- Photo electron peaks become narrower and more clearly separated at larger ϕ-angles
  - probably the electrons after the first MCP hit less capillaries of the second MCP ⇒ less spread





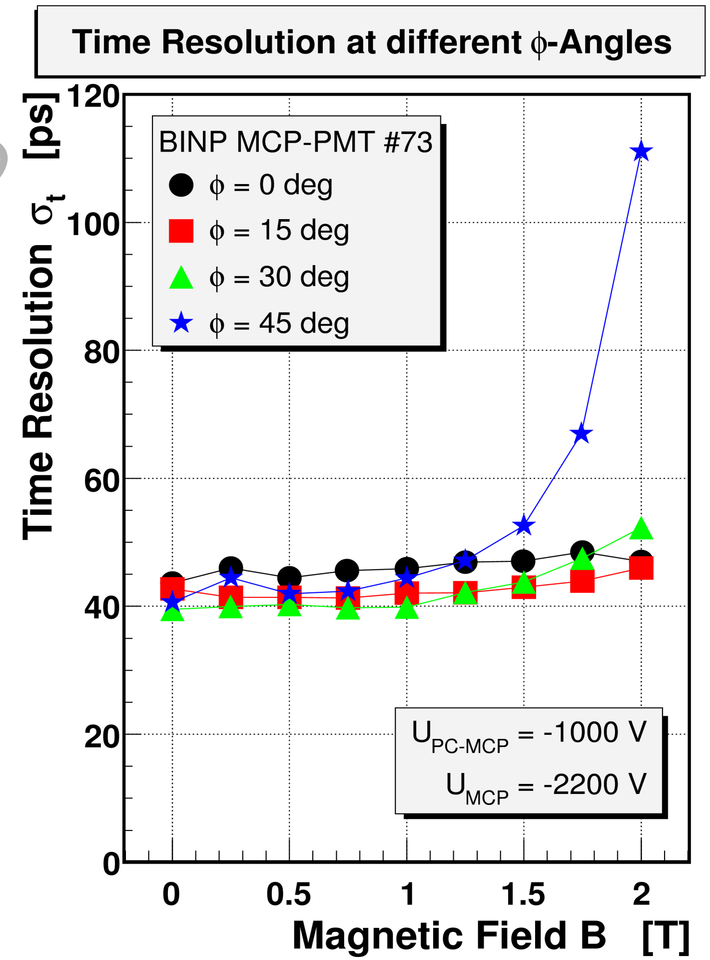
Performance at Different Field Axes

- gain



BINP MCP-PMT #73

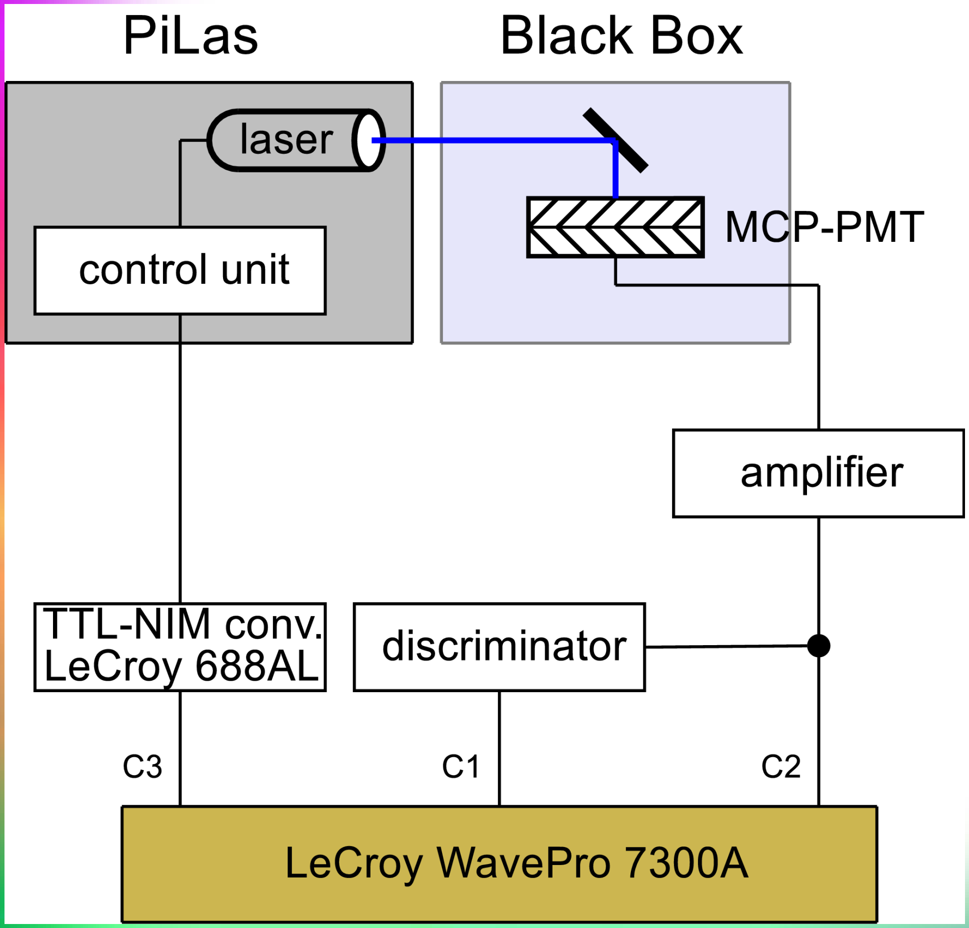
- time resolution (measured)

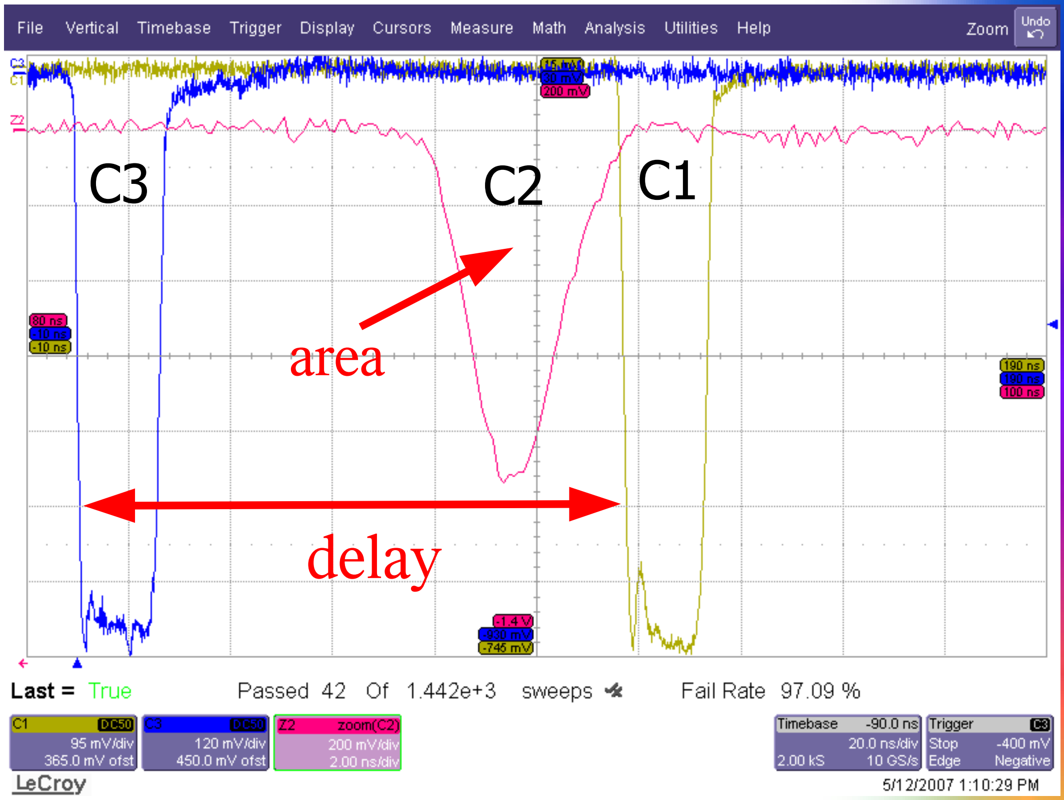


Good gain and excellent time resolution even in 2 Tesla B-field

Timing Measurements with Oscilloscope

- 3 GHz / 20 Gs oscilloscope
- various amplifiers and discriminators tested





- no magnetic field
- delay of PiLas reference pulse C3 to MCP pulse C1
  $\Rightarrow$ jitter $\equiv$ time resolution
- area (C2) to correct time walk

Amplifier and Discriminator Comparison

Time Resolutions in ps (at a gain of 2.5*10^6)

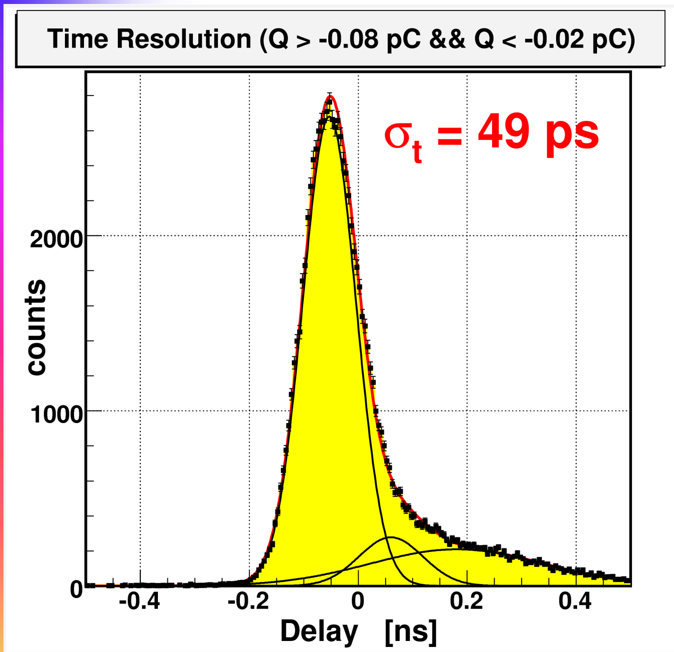
Amplifier		Leading Edge Discriminators: LC 821	LC 620CLR	Constant Fraction Discriminators: CF4000	Ortec 934	Average
Fixed Pulse Height						
	Area in nVs					
Ham. C5594	[-1.2,-0.4]	27.7	33.1	25.9	27.9	**28.7**
Ort. 9306	[-1.2,-0.4]	29.8	34.9	27.9	31.4	**31.0**
Ort. VT120A	[-1.2,-0.4]	30.4	37.7	29.8	31.6	**32.4**
Average		**29.3**	**35.2**	**27.9**	**30.3**	
Single Photons						
	Q in pC					
Ham. C5594	[-0.45,-0.10]	30.5	37.7	27.7	30.7	**31.7**
Ort. 9306	[-0.45,-0.10]	30.2	35.4	27.8	31.2	**31.2**
Ort. VT120A	[-0.45,-0.10]	26.8	33.2	26.5	29.0	**28.9**
Average		**29.2**	**35.4**	**27.3**	**30.3**	

- Best amplifier at fixed pulse height: C5594 (x63, 1.5 GHz)
- Best amplifier for single photons: VT120A (x200, 350 MHz)
- Best discriminator: EG&G ESN CF4000

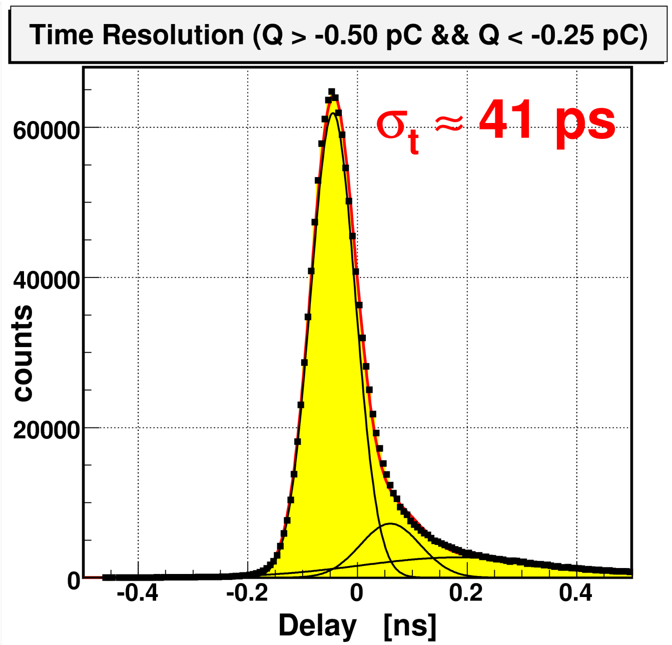
Time Resolution without Magnetic Field

Amplifier Ortec VT120A (x200; 350 MHz) --- Discriminator LeCroy 821

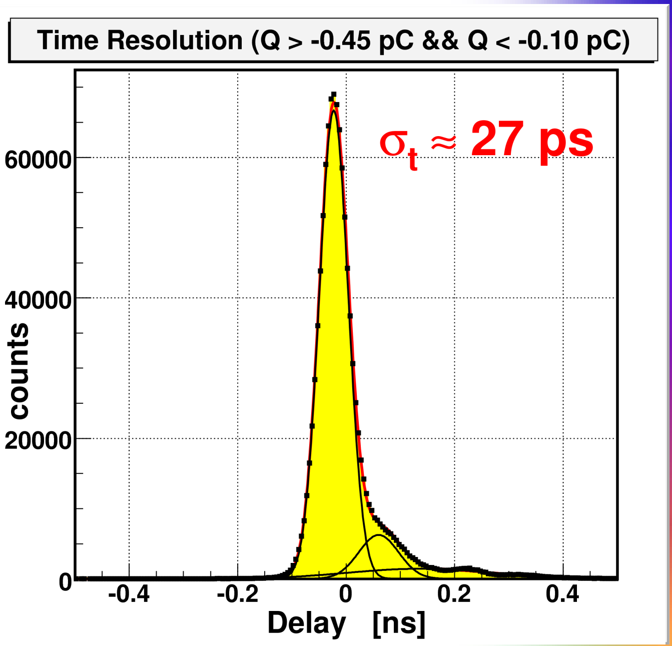
Burle 85011 (25µm)



Burle Prototype (10µm)



BINP #73 (6µm)



- Resolutions corrected for electronics smearing and laser pulse width
  - Burle 85011 (25 µm) **45 ps**
  - Burle Prototype (10 µm) **37 ps**
  - BINP #73 (6 µm) **20 ps**
- Best single photon time resolution with BINP #73

Summary

- measure time-of-propagation (TOP) of Cherenkov photons with PANDA DIRCs
  - with a time resolution of <<100 ps for single photons
  - inside an up to 2 Tesla magnetic field
  - in a >10 MHz rate environment
- several MCP candidates under investigation
  - ~20 ps resolution obtained with 6 μm pore device (from BINP)
  - still to be studied: SL10 (development of Nagoya group in collaboration with Hamamatsu) and others
- perspectives
  - study alternative photon sensors: large-area SiPM (SensL)
  - first DIRC prototypes to be built and tested during 2008
  - design suitable frontend and readout electronics
  - data taking with PANDA in 2015